NA-TECH EVENTS IN THE COASTAL REGION OF SÃO PAULO, BRAZIL: DATA AND FREQUENCY[1]

José Carlos de Moura Xavier [2], Wilson Cabral de Sousa Junior[3]

ABSTRACT: The scientific literature on events involving the loss of containment of hazardous materials due to a natural event (known as na-tech events) is recent and limited in Brazil. Evidence was sought of the occurrence of these events in the coastal region of the state of São Paulo. The study identified fifteen na-tech events between 1940 and 2015, and showed that the events predominantly affected bodies of water. A method was then proposed to estimate the frequency of these events, relativizing them to the number of companies that generated them. Relativization allows the quantitative comparison among locations with different numbers of companies and the transfer of the estimated frequency among locations. The method also allows attributing less uncertain frequency estimates to na-tech accident hypotheses, favoring risk-based decisions. Consistent databases combined with the method allow the construction of na-tech hypotheses appropriate to the location during a quantitative risk assessment of an industrial facility.

Keywords: database, frequency, Na-tech, precipitation, quantitative risk assessment, vulnerability

EVENTOS NA-TECH EN LA REGIÓN COSTERA DE SÃO PAULO, BRASIL: DATOS Y FRECUENCIA

RESUMEN: La literatura científica sobre eventos que involucran la pérdida de contención de materiales peligrosos debido a un evento natural (conocidos como eventos na-tech) es reciente y limitada en Brasil. Se buscaron evidencias de la ocurrencia de estos eventos en la región costera del estado de São Paulo. El estudio identificó quince eventos na-tech entre 1940 y 2015, y mostró que los eventos afectaron predominantemente a cuerpos de agua. Se propuso entonces un método para estimar la frecuencia de estos eventos, relativizándolos al número de empresas que los generan. La relativización permite la comparación cuantitativa entre localidades con diferente número de empresas y la transferencia de la frecuencia estimada entre localidades. El método también permite atribuir estimaciones de frecuencia menos inciertas a las hipótesis de accidentes de na-tech, favoreciendo las decisiones basadas en el riesgo. Las bases de datos consistentes combinadas con el método permiten la construcción de hipótesis na-tech apropiadas para la ubicación durante una evaluación cuantitativa de riesgos de una instalación industrial.

Palabras clave: base de datos, frecuencia, na-tech, precipitación, evaluación cuantitativa de riesgos, vulnerabilidad

INTRODUCTION

The scientific literature on events involving the loss of containment of hazardous materials due to a natural event is recent and limited in Brazil. Nascimento and Alencar (2016) showed, based on a systematic literature review of the 2000-2015 period, the lack of publications by authors affiliated with research institutions in South America. Similarly, Suarez-Paba et at. (2019), who conducted a literature review from 1960-2018, explicitly mentioned only two articles referring to Brazil, including the study by Xavier and Sousa Junior (2016), discussed ahead.

[1] Article received on January 19, 2022 and accepted for publication on May 1, 2022.
[2] Engineer, São Paulo State Environment Company (CETESB), Av. Professor Frederico Hermann Júnior, 345, São Paulo, CEP 05459-900, Brazil. Email: jxavier@sp.gov.br
[3] Professor, Technological Institute of Aeronautics (ITA), Praça Marechal Eduardo Gomes, 50, São José dos Campos, CEP 12228-900, Brazil. Email: wilson@ita.br

These events are known in the scientific literature as na-tech (natural and technological) events, a term coined by Showalter and Myers (1992, 1994), who used it in research on the perception of emergency management agencies of 50 American states regarding the relationship between natural disasters and technological emergencies. Throughout the text, discussing the results of the research, the authors used the term na-tech event when referring to the occurrence of a natural event (earthquake, hurricane, flood, tornado) and the secondary effect of release of hazardous chemical substances to the environment, including of nuclear origin, making a clear distinction between natural events, technological events and na-tech events.

Xavier and Sousa Junior (2016) investigated na-tech events in the strategies of the agencies responsible for the prevention of accidents involving hazardous materials in Brazil. They showed, for example, that the accident databases operated by these agencies, designed to separately record accidents of natural and technological origin, were not prepared to record and quickly retrieve na-tech events. The immediate implication was the limitation in knowing the intensity of the damage caused by na-tech events and estimating their frequency of occurrence and, as a result, not allowing one to both (i) discern the risk posed to humans by na-tech hypotheses in the quantitative risk assessment (QRA) of industrial facilities that handle hazardous materials (the na-tech risk), and (ii) elucidate the potential damage to the environment that is not typically considered in a QRA. Nevertheless, the authors advocated the use of data from Brazilian sources such as the aforementioned Brazilian accident databases, newspapers, and the technical and scientific literature rather than international data in order to estimate the contribution of na-tech events within a QRA.

The interest in clarifying the relevance of na-tech events in Brazil motivated the development of this research. As starting point, it covered the coastal region of the state of São Paulo. The reasons are both the intense industrialization and the environmental characteristics of the region as an annual mean rainfall between 1100 and 1500 mm, with maximum annual rainfalls of greater than 4000 mm, the presence of overlapping soils, and tropical forest covering layers of coastal hills, being subject to the strongest erosion and transport of soil within Brazil (Ab'Sáber, 2005a, 2005b).

The research sought evidence of the occurrence of na-tech events between 1940 and 2015. It also investigated the correlation between the frequency of occurrence of the identified events and rainfall intensity, as well as the need to correct this frequency based on the rainfall trend in the 2007-2040 period for the RCP4.5 and RCP8.5 greenhouse gas emission scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC). Then, based on the identified na-tech events, the na-tech risk and possible damage to the environment were discussed.

This article presents the initial stages of research related to the identification of na-tech events and the estimation of their frequency of occurrence. The other research stages will be presented in due course.

NA-TECH EVENT IDENTIFICATION

The coastal region of the state of São Paulo comprises the municipalities of Bertioga, Cananéia, Caraguatatuba, Cubatão, Guarujá, Iguape, Ilha Bela, Ilha Comprida, Itanhaém, Mongaguá, Peruíbe, Praia Grande, São Vicente, Santos, São Sebastião and Ubatuba. Figure 1 shows the location of these municipalities.

The study was limited to the 1940-2015 period (76 years). The reason for 1940 was to be able to investigate the presence of na-techs before 1955, the date of the beginning of the operation of the Presidente Bernardes Refinery (RPBC, for its acronym in Portuguese), which led to intense industrialization in Cubatão in the following decades. Between 1940 and 1955, there were few industries in the coastal region of São Paulo and four or five in Cubatão.

As a research method, we adopted the reading of regional printed newspapers from the coastal region of the state of São Paulo, reading of the websites of newspapers with state/national coverage and access to the databases of the National Civil Defence, State Civil Defence, São Paulo State Environment Company (CETESB, for its acronym in Portuguese) and Centre for Research on the Epidemiology of Disasters (CRED). The page-by-page reading of printed newspapers sought to find historical evidence of the occurrence of na-tech events. In the websites, the keywords “municipality name” and “flood” were used. In the databases, the keywords “municipality name” and “cause (natural, leak)” were used, and “Brazil” in the CRED database.

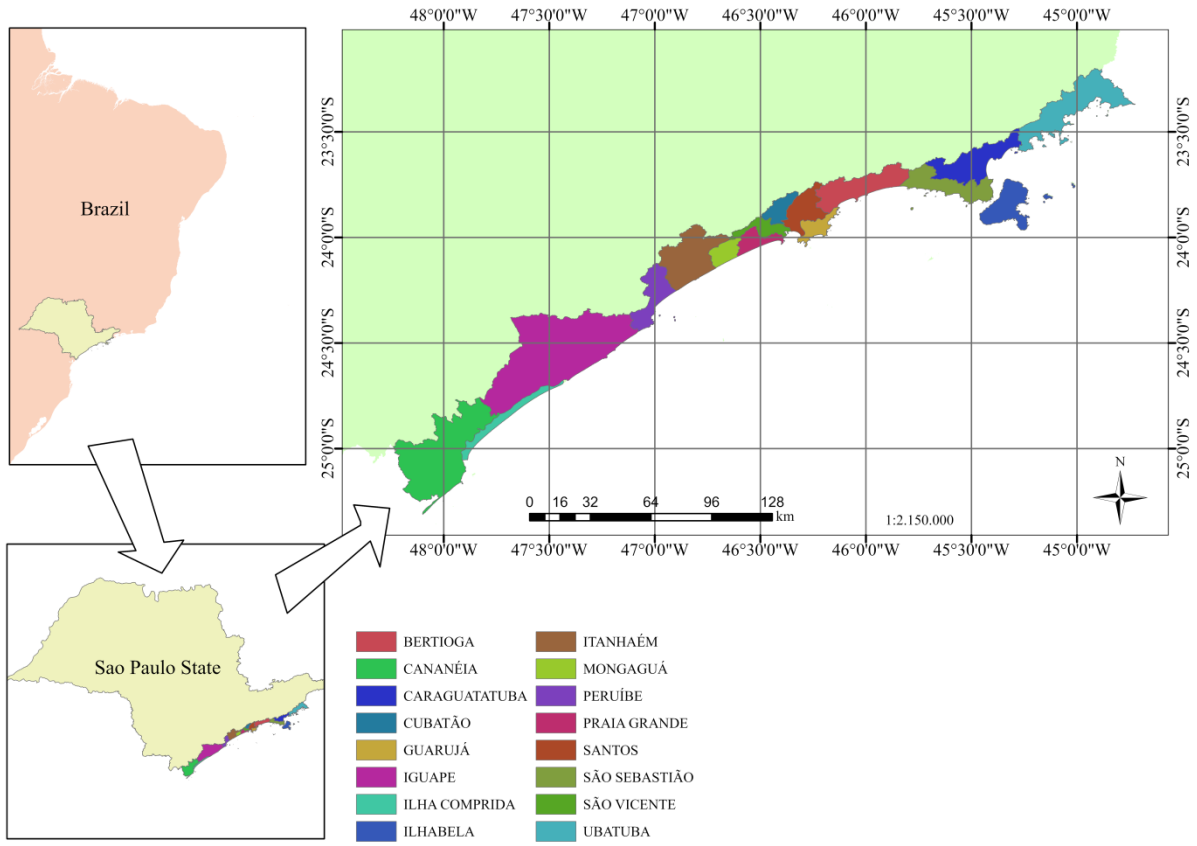

Figure 1: Municipalities of the coastal region of the state of São Paulo.

The search in newspapers proved to be the appropriate option to access old data with accurate date of occurrence of the natural event, since the cited databases did not retrieve events occurring at the beginning of the period of interest and did so in a limited way for the following decades. The approach is similar to that reported by Petrova (2011) on the implementation of a database of technological accidents and disasters in Russia, by Kumasaki et al. (2016), who investigated cascading natural disasters in Japan, or by Chaumillon et al. (2017), who investigated storm-induced marine flooding in France and worldwide.

Approximately 500 reports that mentioned heavy rains, some associated with floods and landslides, were identified. In others, there was mention of strong winds. Some news items appeared in more than one newspaper. There was also some overlap between newspapers and databases, especially the CETESB database.

Based on these news stories, fifteen na-tech events were identified, evidenced by the mention of loss of containment of a reservoir that stored a hazardous material due to a natural event. The appendix and Figure 2 show, by municipality, the na-tech events. There are also twelve news stories that suggest na-tech events, all occurring in Cubatão.

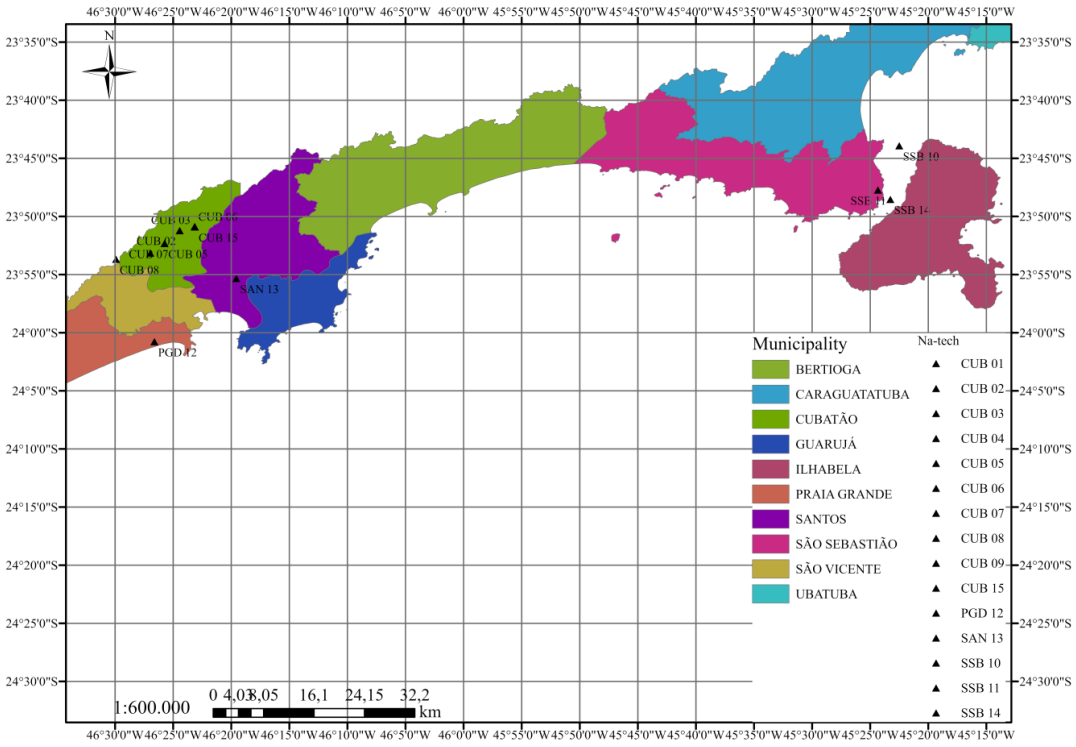

Figure 2: Location of na-tech events in the coastal region of the state of São Paulo.

The reports in the appendix were not refined. Many of them maintain the journalistic language, with emphasis on aspects of the natural event such as impact and time of occurrence. Few of them mention the leaked substances and their quantities. This type of record was preferred to maintain the characteristics of the available information, often conflicting, such as leaked quantities (SSB 10) or equipment where the leak occurred (CUB 05). Refinement can be performed in the future when building a database.

Of the fifteen na-tech events that occurred in the coastal region of São Paulo, ten occurred in Cubatão. The higher incidence in the municipality of Cubatão is compatible with the larger number of companies (25 to 27 starting in the 1980s) compared to São Sebastião (three na-tech events) where there is only one company, although the two municipalities have similar geographic characteristics. The predominance of na-tech events (10 out of 15) occurring in Cubatão combined with the number of companies makes it reasonable to express the occurrence of these events in Cubatão in the period of interest using a quantitative index (a frequency), explained in detail next.

NA-TECH EVENT FREQUENCY

From a methodological perspective, the frequency of occurrence of na-tech events can be estimated similarly to the frequency of pipeline leaks present in *European Gas Pipeline Incident Data Group* (EGIG) and *European Petroleum Refiners Association* (CONCAWE), databases that report leaks in natural gas and oil/oil product pipelines, respectively, in Europe. For example, EGIG (2018) reports a frequency of 0.31 annual occurrences per 1000 km of pipeline. This estimate results from the record of 1366 occurrences during the 1970-2016 period in approximately 143,000 km of pipelines (current length), equivalent to an exposure in the period of 4.41E + 03 km×year.

Following a similar reasoning, where the number of leaks is normalized by the length of the pipelines, equation 1 allows estimating TN_n, the frequency of occurrence of na-tech events accumulated over time and normalized by the number of companies based on the chronological ordering of the events in the 1940-2015 period.

The underlying reasoning for normalization derives from the definition of a na-tech event, i.e., it only occurs in the presence of at least one company, from which there will be loss of containment of the hazardous material. This logic is evident in Santella et al. (2011) or Girgin and Krausmann (2016).

$$TN_n = \left(\sum_{i=1}^{n} \frac{N_i}{E_i}\right) \left(\sum_{i=1}^{n} P_i\right)^{-1} \quad (1)$$

where (i) period of interest, (N_i) number of na-tech events in period i, (E_i) number of companies in period i and (P_i) number of years in each period i.

As a premise, the equation 1 requires independent na-tech events. Based on the employment of the term na-tech by Showalter and Myers (1992, 1994), the independence is reached by assigning only one identifier code (see the first column in the appendix) for each natural event regardless the number of secondary effects, i.e., the releases of hazardous materials to the environment (or the technological events).This approach can be observed in both SAN 13 and CUB 08 na-tech events mentioned in appendix. The first one indicates a natural event (lightning) and a cascading secondary event involving three storage tanks. The second, CUB 08, reports a natural event (heavy rain) and secondary events in three different locations.

To determine the TN_n for Cubatão, the period 1940-2015 (76 years) was divided into five-year periods, except for the first period which comprised six years. The periods were chosen after applying the method proposed by Sturges (1926). The initial fifteen-year periods derived from the method were reduced for five-year periods after exploring na-tech events distribution and the number of companies in different periods. The number of na-tech events and companies in each period was determined, and the frequency was calculated using equation 1. Table 1 shows the estimated TN_n.

Table 1: Frequency of occurrence of na-tech events in Cubatão accumulated over time and normalized by the number of companies (TN_n).

i	P_i	E_i	N_i	Event in the period (occurrence/ company × year)	TN_n (occurrence/ company × year)
1940-1945	6	4	0	0	0
1946-1950	5	4	0	0	0
1951-1955	5	5	0	0	0
1956-1960	5	11	0	0	0
1961-1965	5	12	0	0	0
1966-1970	5	15	0	0	0
1971-1975	5	21	0	0	0
1976-1980	5	28	0	0	0
1981-1985	5	27	2	1.48E-02	1.61E-03
1986-1990	5	27	2	1.48E-02	2.90E-03
1991-1995	5	27	1	7.41E-03	3.31E-03
1996-2000	5	26	2	1.54E-02	4.30E-03
2001-2005	5	26	0	0	3.97E-03
2006-2010	5	25	0	0	3.69E-03
2011-2015	5	25	3	2.40E-02	4.97E-03

Legend: (i) period of interest, (P_i) number of years in each period i, (E_i) number of companies in period i, and (N_i) number of na-tech events in period i.

The frequency is increasing and reflects the record of na-tech events starting in the 1981-1985 period. Since then, zero to three occurrences per period have been observed, with a temporal trend shown in Figure 3. The frequency point value, e.g., 4.97E-03 occurrence/company × year, indicates the number of na-tech events normalized by the number of companies present in each period and counted over the entire period of interest.

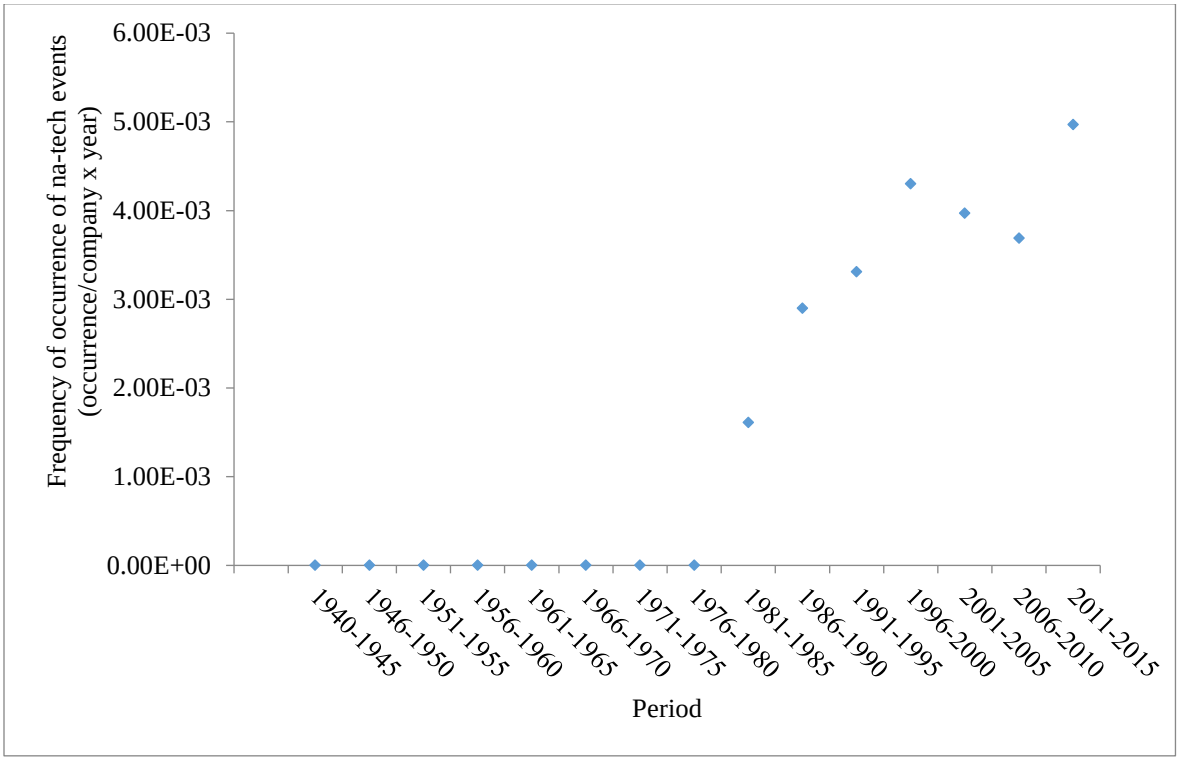

Figure 3: Frequency of occurrence of na-tech events in Cubatão.

Next, similar to the QRA of pipelines, where the frequencies of the accidental hypotheses are estimated from databases such as EGIG and CONCAWE (BSI, 2009; CETESB, 2014), a hypothesis related to the loss of containment of equipment due to a natural event can be formulated and the frequency (TN_n) assigned to it as an estimate of the frequency of occurrence of the hypothesis.

NA-TECH EVENT DAMAGE

In the na-tech events identified in the coastal region of São Paulo, there is no mention of people affected by fire, explosion or atmospheric dispersion of the substances. There is no mention of monitoring of the water bodies in the days following na-tech events, although it is reasonable to infer some damage to the fauna near the leak sites.

The absence of human fatality was also noted by Girgin and Krausmann (2016) when investigating the occurrence of na-tech events in the onshore pipeline network for the transport of hazardous liquids in the United States between 1986 and 2012. This finding is relevant because the metric adopted in the QRA to express risk has as reference values (or end points) toxic substance concentrations, thermal radiation intensity or overpressure intensity sufficient to cause human fatality.

The finding that water bodies were affected by the leaks is in line with the findings of Cozzani et al. (2010), who, in a survey of European and American databases, identified water contamination as the most

recorded effect. Girgin and Krausmann (2016), in turn, showed that 48% of na-tech events resulted in releases to the ground, 28% to water bodies and 14% to the atmosphere.

From the appendix, Table 2 was constructed, which contains the substances and equipment involved in the spills, in addition to the immediate causes of the spills.

Eight of the fifteen na-tech events have floods as an immediate cause. Soil movement was the immediate cause of four na-tech events. Wind, stream, rainfall and lightning also appear as immediate causes.

The floods reached open equipment installed at ground level, as in the case of effluent treatment stations and storage sheds. These equipments can be added to those identified by Cozzani et at. (2010) and suggest, due to their construction and location characteristics, a higher probability of loss of containment.

Nevertheless, regarding the equipment, there is no report of the involvement of pressurized tanks, and only SAN 13 mentions an atmospheric tank hit by lightning.

The na-tech event SAN 13 affected two tanks, where the first was hit by lightning and the second by a domino effect resulting from the explosion and movement of the roof of the first tank.

Table 2: Equipment and substances involved in na-tech events.

Identifier	Date	Substance leaked	Equipment	Immediate cause
CUB 01	01.25.1985	Ammonia	Pipeline	Land slide
CUB 02	03.09.1988	Tail gas	Pipeline	Land slide
CUB 03	02.05.1989	Ammonia	Pipeline	Land slide
CUB 04	01.16.1992	Oily waste	Effluent treatment station	Flood
CUB 05	02.08.1998	Oily waste	Effluent treatment station	Flood
CUB 06	01.11.1999	Unidentified	Solids storage warehouse (supposedly)	Flood
CUB 07	01.15.2011	Oily waste	Effluent treatment station	Flood
CUB 08	02.22.2013	Oily waste	Effluent treatment station (site 1)	Flood
		Oily waste	Effluent treatment station (site 2)	Flood
		Chlorine	900kg cylinder (site 3)	Land slide
CUB 09	03.17.2013	Oily waste	Effluent treatment station	Flood
SSB 10	03.18.1974	Crude oil	Ship tank	Wind and stream
SSB 11	01.14.2010	Oily waste	Filter drainage tanks	Rainfall
PGD 12	04.13.2007	Diesel	Underground tanks	Flood
SAN 13	10.10.1991	Acrylonitrile, hexane	Vertical atmospheric tank	Lightning
SSB 14	08.19.1976	Crude oil	Unloading arms	Wind
CUB 15	02.01.1983	Sulphate, Urea (??)	Solids storage warehouse (supposedly)	Flood

The loss of containment of the toxic gases ammonia and chlorine in na-tech events CUB 01, CUB 03 and CUB 08 suggests the possibility of harm to humans, although the records mentioned only odour perception in CUB 08.

DISCUSSION

Seven of the 15 na-tech events were identified in the CETESB database (CETESB 2022). Another seven by reading the *A Tribuna* printed newspaper and one on the website of the *Folha de São Paulo* newspaper (Folha de São Paulo, 2022). Only three events had concurrent records in two sources.

The underreporting noted by Rasmussen (1995) or the identification of the na-tech event only after an intense examination of records reported by Girgin and Krausmann (2016) were also identified in this study. For example, in the na-tech event CUB 08, the *A Tribuna* newspaper did not mention the dragging of five chlorine cylinders and the loss of content from one of them (underreporting). Additionally, na-tech event CUB 07 was located after personally consulting the Emergency Response Sector of CETESB and using the keyword "overflow" to search its database (identification).

Despite the lack of a specific database for na-tech events, the existing databases, such as those of CETESB, National Civil Defence (Brazil, 2021) and State Civil Defence of São Paulo (São Paulo, 2022), do not have search keywords with immediate association with this type of event. In the case of the CETESB database, events were identified through searches with keywords such as overflow, tank or pipeline transport, different from the expected for an event triggered by a natural cause. The keyword "natural" was introduced in 2012 and allowed retrieval of three records, all na-tech events.

Specific databases, such as the one managed by the Joint Research Centre (JRC) (European Commission, 2011), a European Union research center, allow the targeted search of these events. The counterpoint is the need to feed these databases with past records for statistical analysis. Alternatively, the existing databases can be improved (Xavier and Sousa Junior, 2016) by inserting search keywords that lead directly to na-tech events. In the same way as for a specific database, the existing records should be reviewed to qualify them based on the new search keyword.

The systematic recording of these events makes it possible to broaden the analysis of their occurrence on the temporal and spatial scales in order to determine the damage states and the frequency of occurrence, which are essential for a QRA of an industrial facility that handles hazardous materials installed in an area prone to occurrence of na-tech events. It would also help to determine the contribution of these events to the risk imposed by the facility on humans and to elucidate possible damages to the environment that are not commonly considered in a QRA.

Normalizing the frequency of occurrence of na-tech events by the number of companies allows to properly compare the frequency of events occurring in Cubatão with those estimated for locations with greater or lesser presence of companies. It also allows attributing less uncertain frequency estimates to na-tech accidental hypotheses, which favours risk-based decision making.

Unlike hypotheses whose causes are attributed to human or equipment failures, as occurs in traditional QRA, with numerical probability and frequency values that can be used in industrial facilities located in different countries, na-tech hypotheses consider local and regional specificities such as the geographic, hydrological and industrial and occupation characteristics. Therefore, the frequency of occurrence of na-tech events is limited to Cubatão and its surroundings and shows a growing trend, as indicated in Figure 3. Adopting the values found for other regions is not recommended but adopting the proposed method is, as it can guide other estimates, preferably at the local or regional level, so that they reflect the characteristics of regions.

The research did not identify reports of injured or dead people. It did find that na-tech events predominantly affected water bodies close to companies. Therefore, this risk should be managed, regardless of the metric used for its expression.

For Cubatão, the strategy for the protection of industrial enterprises established in 1986 and still in force with the creation of the special commission for the restoration of Serra do Mar region in Cubatão should be expanded. The commission proposed that year a contingency plan to monitor the amount of rainfall and adopt measures in companies potentially affected by landslides (São Paulo, 1986).

Landslides are not the main cause of na-tech events in Cubatão. As shown in Table 2, six of the ten events that occurred in the municipality resulted exclusively from floods and affected open equipment installed at ground level.

Therefore, the public and private management of the Cubatão industrial park should also include the identification of flood-prone regions and observation of the presence of equipment storing or processing hazardous substances. Equipment installed at ground level and near water bodies should take priority in protection using physical barriers or be moved to suitable locations.

The results of the research can be used in the decision-making processes of companies and regulatory agencies. Companies, as already mentioned, can assist in the location of the new projects or in the management of the existing projects. For regulatory agencies, this is an important result in that it expands the scope of the QRA, even though the metrics of that tool do not consider the impacts on environmental goods other than humans but which are observed in the identified na-tech events.

These results can be improved by expanding databases with records from other sources. It is understood that the companies involved in na-tech events can contribute accurate information about the equipment involved, the amounts of substances released into the environment, the measures adopted before and after the na-tech event, the damage to human life and to other environmental goods, economic impacts and effects on the company's image and, last, the lessons learned. This information is relevant for understanding the dynamics of na-tech events, estimating na-tech risk and proposing management measures.

CONCLUSIONS

The fifteen na-tech events presented in the appendix and twelve other suggestive reports confirm the initial interest of the research regarding the occurrence of na-tech events in the industrialized areas of the coastal region of São Paulo.

The difficulty in identifying these events, as well as the observed increasing trend in the number of na-tech events, reinforces the need for Brazilian accident databases to include these events, making it possible to broaden the discussion about their relevance in the risk to humans imposed by enterprises that handle hazardous materials in places prone to the occurrence of na-tech events.

The proposed method for estimating the frequency of occurrence, which relativizes the events found by the number of companies that generated them, is relevant because it allows the quantitative comparison of locations or regions with different numbers of companies. The comparison and eventual adoption of the numerical value will be more robust if these locations or regions have similar geographic, hydrological and industrial land occupation characteristics.

Consistent databases combined with the proposed method for frequency estimation will allow the construction of na-tech hypotheses appropriate to the location or region in which a traditional QRA is performed, making it possible to determine the contribution of these hypotheses to the risk imposed by companies to humans.

REFERENCES

Ab'Sáber, A.N. (2005ª). Os domínios de natureza do Brasil: potencialidades paisagísticas [The domains of nature in Brazil: landscape potential], São Paulo: Ateliê Editorial 3rd ed.

Ab'Sáber, A. N. (2005b). Litoral do Brasil [Brazilian Coastline], São Paulo: Metalivros.

Ministério da Integração Nacional. (2021). Sistema Integrado de Informações sobre Desastres – S2iD, accessed Oct 18, 2021 at:. https://s2id-search.labtrans.ufsc.br/.

BSI, British Standard Institution. (2009). BSI PD 8010-3:2009. Steel pipelines on land - Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major accident hazard pipelines containing flammables.

CETESB. (2014). Risk of accident of technological origin. Method for decision-making and reference terms, accessed May 06, 2022 at: https://sistemasinter.cetesb.sp.gov.br/normas/11/2013/11/P4261.pdf.

CETESB. (2022). Sistema de Informações sobre Emergências Químicas, accessed May 06, 2022 at:.https://sistemasinter.cetesb.sp.gov.br/emergencia/relatorio.php.

Chaumillon, E.; Bertin, X.; Fortunato, A. B.; Bajo, M.; Schneider, J. L.; Dezileau, L.; Walsh, J. P.; Michelot, A.; Chaveau, E.; Créach, A.; Hénaff, A.; Sauzeau, T.; Waeles, B.; Gervais, B.; Jan, G.; Baumann, J.; Breilh, J. F.; Pedreros, R. (2017). *Storm-induced marine flooding: Lessons from a multidisciplinary approach, Earth-Science Reviews*, v. 165, 151-184. http://dx.doi.org/10.1016/j.earscirev.2016.12.005.

Cozzani, V.; Campedel, M.; Renni, E.; Krausmann, E. (2010). "Industrial accidents triggered by flood events: analysis of past accidents", *Journal of Hazardous Materials*, v. 175, 501–509. https://doi.org/10.1016/j.jhazmat.2009.10.033.

EGIG. (2018). EGIG gas pipeline incidents: 10th Report of the European Gas Pipeline Incident Data Group (period 1970–2016), accessed May 06, 2022 at:. https://www.egig.eu.

European Commission. (2011). *Natech accident database*, Joint Research Centre, Institute for the Protection and Security of the Citizen, Italy, accessed May 06, 2022 at: https://enatech.jrc.ec.europa.eu/.

Folha de São Paulo. (2022). São Paulo: UOL, 1921, accessed May 06, 2022 at: http://acervo.folha.uol.com.br/.

Girgin, S.; Krausmann, E. (2016). "Historical analysis of U. S. onshore hazardous liquid pipeline accidents triggered by natural hazards", *Journal of Loss Prevention in the Process Industries*, v. 40, 578-590. http://dx.doi.org/10.1016/j.jlp.2016.02.008.

Kumasaki, M.; King, M.; Arai, M.; Yang, L. 2016. Anatomy of cascading natural disasters in Japan: main modes and linkages. Natural Hazards, v. 80, 1425-1441. DOI 10.1007/s11069-015-2028-8.

Nascimento, K. R. da S.; Alencar, M. H., (2016). "Management of risks in natural disasters: a systematic review of the literature on NATECH events", *Journal of Loss Prevention in the Process Industries*, v. 44, 347-359. http://dx.doi.org/10.1016/j.jlp.2016.10.003.

Petrova, E. G. (2011). Natural factors of technological accidents: the case of Russia. Natural Hazards and Earth System Sciences, v. 11, 2227–2234. https://doi.org/10.5194/nhess-11-2227-2011.

Poffo, I. R. F. (2000). Vazamentos de óleo no Litoral Norte do estado de São Paulo: análise histórica (1974 a 1999). Master's Dissertation, University of São Paulo, Brazil, 2000, accessed May 06, 2022 at: https://cetesb.sp.gov.br/emergencias-quimicas/wp.

Rasmussen, K. (1995). "Natural events and accidents with hazardous materials", *Journal of Hazardous Materials*, v. 40, 43-54. https://doi.org/10.1016/0304-3894(94)00079-V.

Santella, N.; Steinberg, L. J.; Aguirra, G. A. (2011). "Empirical estimation of the conditional probability of na-tech events within the United States", *Risk Analysis*, v. 31, (6), 951–968. https://doi.org/10.1111/j.1539-6924.2010.01561.x.

São Paulo. (1986). Comissão Especial para a Restauração da Serra do Mar na Região de Cubatão. Plano de Ações de Emergência 1985/1986: Relatório de Situação. Printed copy available at CETESB library

São Paulo. (2022). Governo do Estado de São Paulo. Sistema Integrado de Defesa Civil – SIDEC, accessed May 06, 2022 at:. http://www.sidec.sp.gov.br/. (in Portuguese)

Showalter, P. S.; Myers M. F. (1992). Natural disasters as the cause of technological emergencies: a review of the decade 1980–1989. Working paper 78. Natural Hazards Research and Applications Information Center. Institute of Behavioral Science. University of Colorado.

Showalter, P. S.; Myers M. F. (1994). "Natural disasters in the United States as release agents of oil, chemicals, or radiological materials between1980–1989: analysis and recommendations", *Risk Analysis*, v. 14, (2), 169–182.

Sturges, H. A. (1926). "The choice of a class interval", *Journal of the American Statistical Association*, v. 216, n. 153, 65-66.

Suarez-Paba, M. C.; Perreur, M.; Munoz, F.; Cruz, A. M. (2019). "Systematic literature review and qualitative meta-analysis of Natech research in the past four decades", *Safety Science*, v. 116, 58-77. https://doi.org/10.1016/j.ssci.2019.02.033.

Xavier, J. C. de M.; Sousa Junior, W. C. (2016). Recognising na-tech events in Brazil: moving forward. Natural Hazards (Dordrecht), v. 82, 493-506. https://doi.org/10.1007/s11069-016-2194-3.

APPENDIX
Identified na-tech events

Identifier	Date	Municipality	Location		Company	Description
			UTM-N	UTM-E		
CUB 01	01.25.1985	Cubatão	7361270	356682	Ultrafértil	Rupture of a three-inch pipeline transporting ammonia between Ultrafértil's Jardim São Marcos and Fafer units. Leakage of 15t in approximately three hours due to landslide resulting from rainfall. It occurred at 11:45 pm at km 60 of Piaçaguera-Guarujá highway, at Sector 8.
CUB 02	03.09.1988	Cubatão	7361270	356682	Copebras/ Union Carbide	Small leaks of tail gas in a pipeline that connects Copebras to Union Carbide due to landslide. Detection occurred during testing of the pipeline performed prior to its operation. The leaks occurred at dawn, at km 60 of Piaçaguera-Guarujá highway, in Sector 8.
CUB 03	02.05.1989	Cubatão	7361270	356682	Ultrafértil	Rupture of a three-inch pipeline transporting ammonia between Ultrafértil's Jardim São Marcos and Fafer units. It resulted from landslide. It occurred at km 60 of Piaçaguera-Guarujá highway, in Sector 8.

APPENDIX
Identified na-tech events (continued)

Identifier	Date	Municipality	Location		Company	Description
			UTM-N	UTM-E		
CUB 04	01.16.1992	Cubatão	7359213	354505	Petrobras	Heavy rain led to the overflow of Cubatão River. Its waters reached the effluent treatment station of Presidente Bernardes Refinery (RPBC). The contaminated waters reached the residences of Vila Elizabeth, near the RPBC. Over the past 72 hours, rainfall in the region of the refinery reached 342 mm. Peak rainfall in Cubatão occurred at 4 pm with 147.4 mm (1 h). Approximately 1000 people were forced out of their homes, mainly in Vila Parisi and Morro Mazargão.
CUB 05	02.08.1998	Cubatão	7359213	354505	Petrobras	Heavy rain caused the overflow of oily waters from the RPBC effluent treatment station, which reached the Cubatão River. The leaked volume was not reported or estimated. According to CETESB, (i) the spill impregnated with oil an approximately 5-km extension of the right bank of Cubatão River; (ii) preliminary evaluation indicated severe damage to the environment and (iii) the leakage resulted from the operation of only two of the five pumps that control the arrival of oil in the treatment station. According to Petrobras, the spill had no connection with the pumps. It was due to the rupture of the lid of a passage box through which runs a pipeline carrying oil to the treatment station.

APPENDIX

Identified na-tech events (continued)

Identifier	Date	Municipality	Location		Company	Description
			UTM-N	UTM-E		
CUB 06	01.11.1999	Cubatão	7361874	358913	Solorrico	Heavy rain associated with the opening of the floodgates of the Billings dam flooded part of the Cubatão industrial complex. The opening contributed to the partial flooding of the company and of the main access roads to the complex. The flooding was also due to restrictions to the flow of Piaçaguera River, near Solorrico. A note from the company reported that at 5 pm its industrial area was threatened by water, with material losses.
CUB 07	01.15.2011	Cubatão	7359213	354505	Petrobras	Heavy rain led to the overflow of the waste retention pond of the RPBC effluent treatment station.

APPENDIX

Identified na-tech events (continued)

Identifier	Date	Municipality	Location		Company	Description
			UTM-N	UTM-E		
CUB 08	02.22.2013	Cubatão	7359213	354505	Petrobras	Heavy rain caused (i) flooding of the RPBC areas, including the effluent treatment station (industrial wastewater treatment station and effluent accumulation basin), carrying oily material to Cubatão River; (ii) mudslide and a landslide at Serra do Mar near the Pilões water treatment station of Sabesp. Among the consequences, there was the dragging of five chlorine storage cylinders with individual storage capacity of 900 kg. The cylinders were recovered from the water bodies of the region. One of them had a ruptured valve and lost its contents. There were complaints of odour from the Vila dos Pescadores community; and (iii) flooding of Transpetro's Cubatão Terminal. As a result, there was flooding of the water-oil separator (WOS), pump house, sump tank and rupture of the levees of tanks TQ 14011 and TQ 14023. There was mud accumulation in the WOS, sump tank and waste yard, with drums carried from this yard to the street (Pescada Street) and accumulation of debris contaminated with oily sludge. On February 25,500 people were temporarily forced out of their homes and 4,000 were made homeless.
			7356622	347438	Sabesp	
			7357676	352436	Transpetro	

APPENDIX
Identified na-tech events (continued)

Identifier	Date	Municipality	Location		Company	Description
			UTM-N	UTM-E		
CUB 09	03.17.2013	Cubatão	7359213	354505	Petrobras	Heavy rain caused flooding of the RPBC areas, including the effluent accumulation basin of the effluent treatment station, carrying oily sludge to Cubatão River.
SSB 10	03.18.1974	São Sebastião	7375331	461814	Transpetro	Strong winds and stream led to the breaking of the moorings of the Takamiya Maru tanker, from Japan, and Conoco Canada tanker, of Liberian flag, at approximately 11 am, which were anchored next to the piers of the São Sebastião Waterway Terminal (TA/SSE). The Conoco, after hitting a rock, drifted and ran aground on a sand bank near Ilha Bela municipality. The Takamiya, which also hit the rock, had a broken hull and, according to the *Folha de São Paulo* newspaper, poured approximately 15t of oil into the sea. In turn, the newspaper *A Tribuna* reported 15,000t and Poffo (2000) reported a leakage of 6,000t.
SSB 11	01.14.2010	São Sebastião	7368370	458685	Transpetro	Heavy rain caused the overflow of the surge tank of the auxiliary filters' drainage tanks of the OSVAT pipeline located at TA/SSE. A small amount of oily sludge reached Outeiro creek, which flows into São Sebastião Channel.

APPENDIX
Identified na-tech events (continued)

Identifier	Date	Municipality	Location		Company	Description
			UTM-N	UTM-E		
PGD 12	04.13.2007	Praia Grande	7343599	353177	Centro Automotivo Veraneio	Heavy rain caused flooding of the three tanks of this gas station. The gas station was deactivated, and the tanks' lids were opened, removed by vandals. The leaked product was diesel oil, which flowed to the nearby rain water drains.
SAN 13	10.10.1991	Santos	7353785	365022	Granel Química	Lightning sparked a fire in two 1,400m^3tanks shortly after 6:30 a.m. The lightning hit tank 51, containing 500t of acrylonitrile. An explosion followed, and the tank's roof hit and ruptured a valve in tank line 57, which contained hexane. The hexane jet hit tank 61, which was partially destroyed. There were no victims.
SSB 14	08.19.1976	São Sebastião	7366873	460582	Transpetro	Winds of up to 110 km/h broke the moorings of the Energy Transmission tanker, of Liberian flag, anchored on the TA/SSE pier, at approximately 7:40 a.m. Three of the five unloading arms broke, and oil spilled into São Sebastião Channel.
CUB 15	02.01.1983	Cubatão	7361874	358913	Solorrico	Heavy rain led to the overflow of the Piaçaguera River. Rainfall fell more intensely after 4:00 am. At 5:00 am, the waters reached 50cm in the industrial and administrative area of the company, flooding the raw material storage and production sectors, forcing it to stop fertilizer production. Tons of urea and sulphate were lost.

AUTHORS BIOSKETCH

J. de Moura-Xavier

Graduated in chemical engineering; pharmacy and biochemistry from University of São Paulo, Brazil. He obtained a Master and Doctorate in Science both from Technological Institute of Aeronautics. Actually, he works at *São Paulo State Environment Company* in activities related to risk management of industrial enterprises that handle hazardous materials.

W. de Sousa-Junior

Associate professor at Technological Institute of Aeronautics working mainly on the following topics: environmental and ecological modeling, enviromental management instruments, economic-environmental analysis of infrastructure projects and climate change. He is graduated in oceanology with a Master in remote sensing and Doctorate in economics. Also, he works as a professor at the graduate program in natural disasters at São Paulo State University and coordinate the HabITAs project, which aims to break paradigms in Brazilian civil construction towards sustainability. Author of the book “Water management in Brazil: reflections, diagnoses and challenges”, among other.